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Eucyclops serrulatus Species Group (Copepoda: Cyclopoida: Cyclopidae) from Korea

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ABSTRACT

A taxonomic study on the *Eucyclops serrulatus* species group has been accomplished as one of the serial researches on the freshwater cyclopoid copepods in Korea. As a result, the '*Eucyclops serrulatus*', hitherto known from Korea through many reports and papers, turns out to be a species complex of six sibling species: *E. serrulatus* (Fischer), *E. roseus* Ishida, *E. speratus* (Lilljeborg), *E. pacificus* Ishida, *E. ohtakai* Ishida, and *E. tsushimensis* Ishida. Taxonomic accounts on their detailed interspecific discrepancies and intraspecific variabilities are presented. A key to the *Eucyclops serrulatus* group from the Far East is also provided.

Key words: taxonomy, *Eucyclops serrulatus* group, Cyclopidae, freshwater Copepoda, Korea

INTRODUCTION

Genus *Eucyclops* is the most representative freshwater cyclopoid copepods, mainly inhabiting eutrophicated waters. Among the *Eucyclops* species, *E. serrulatus* (Fischer, 1851) has been known as cosmopolitan (Dussart and Defaye, 1985), and reported from the various habitats

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including ricefields, ponds, reservoirs, lakes, swamps, rivers, streams, mountain waters, wells, and brackish waters. In Korea, since the limnological report by Cho (1965) from the Han River, numerous reports mentioned the '*E. serrulatus*' in the collection list. Kim and Chang (1989) and Yoo and Lim (1989) first dealt with the species taxonomically in their faunistic study on the freshwater cyclopoid copepods from Korea. However, the '*E. serrulatus*' in the papers above must have been misidentified or mixed up with more than one cryptic species, for their identifications were based on the old 'macrocharacters' (Van de Velde, 1984). Therefore, the true *Eucyclops* fauna in Korea still has been remained entirely unclear.

Recently *E. serrulatus* is supposed to be the species complex composed of many cryptic species. In Japan, Ishida (1997, 2000, 2001, 2002) clarified that the *E. serrulatus* species group comprises seven sibling species (unpublished data). As a result of the faunistic research on the freshwater cyclopoid copepods in Korea performed since 1995, the authors confirmed the existence of the species complex, and identified six sibling species belonging to the species group.

The accurate identification of zooplanktons including cyclopoid copepods is one of the indispensable prerequisites for limnological study and the various works for nature conservation. However, the morphological characters of freshwater cyclopoid copepods like genera *Eucyclops* and *Mesocyclops* are so delicate and subtle that even the experienced specialists can only identify the sibling species under the microscope with high power resolution after dissecting the mouthparts. Moreover, they often exist as the pre-maturing copepodite stage IV or V mixed with adults, or as only copepodites in the diapause season. As the genetic variations of mitochondrial *cytochrome c oxidase* subunit I (COI) and the competitive species-specific PCR is known to be a useful tool as molecular markers for the realtime environmental assessment on the copepods at all their life stage (Bucklin et al., 1999), so we have tried to develop molecular bio-markers for the freshwater cyclopoid copepods from Korea. In the molecular analyses, all of the representative taxa of Korean *serrulatus* group were distinctly separated into the six species groups. This relationship is highly congruent with that inferred using morphological criteria.

In the course of preparing the genetic data from the pre-identified one-individual specimens, we found various intraspecific variations existed in the 'microcharacters' of each sibling species of *serrulatus* group. Meanwhile, through the genetic analyses, the accurate taxonomic identification on the six sibling species from Korea could be verified, and the ranges of intraspecific morphological variations of each sibling species could be re-assessed. In this paper, only the taxonomic accounts on the interspecific morphological differences between the sibling species and their intraspecific variabilities are presented. As for the genetic characteristics of the *E. serrulatus* species group including the genetic validity of each cryptic species and their phylogeny are to be given under the separate paper.

MATERIALS AND METHODS

Samplings were made with a dipnet of no. 25 mesh aperture from the various freshwater bodies in Korea. Copepods were fixed and stored in 4% buffered formalin for morphological study and in 95% ethanol for genetic purposes. Specimens were dissected and mounted in lactophenol on H-S

slide (Shirayama et al., 1993), a recent variation of Cobb slide, then observed using a differential interference contrast microscope (Olympus BX51) equipped with Nomarski optics. All drawings and measurements were made with the aid of a camera lucida.

The SEM material was prefixed for 6 hours at 4°C with 2.5% paraform-glutaraldehyde, then followed by postfixation with 2% cold osmium tetroxide for 1.5-2 hours. After dehydration through a graded series of ethanol (50-100% at 10% intervals) for 30 minutes each, the material was critical point dried, coated with lead and platinum-palladium in a high evaporator, and then examined in a Hitachi S-4300 scanning electron microscope operated at 15 KV.

Abbreviations used in the text and figures follow the conventional ones frequently used in the taxonomy of freshwater cyclopoid copepods: A1, antennule; A2, antenna; Fu, furcal branches (caudal rami); Md, mandible; Mxl, maxillule; Mxa, maxilla; Mxp, maxilliped; Op, anal operculum; P1-5, legs (peraeopods) 1-5; enp1-3 or exp1-3, the first to third endopodal or exopodal segment of each leg. Main collectors of the material examined are initialized as follows: C. Y. Chang as CYC, H. W. Lim as HWL, J. M. Jeon as JMJ, and J. M. Lee as JML.

TAXONOMIC ACCOUNTS

Family Cyclopidae Sars, 1913
Subfamily Eucyclopinae Kiefer, 1927
Genus *Eucyclops* Claus, 1893

1. **Eucyclops roseus* Ishida, 1997 (Figs. 1-3)

Eucyclops roseus Ishida, 1997, p. 350, figs. 1-3; Ishida, 1998, p. 24; Ishida and Hiruta, 1999, p. 90; Ishida, 2002, p. 47, fig. 12.

Eucyclops serrulatus: Kim and Chang, 1989 (in part.), p. 232; Yoo and Lim, 1989, p.131, pl. 6, figs. 1-8; Ishida et al., 1991, p. 63.

Eucyclops speratus: Ishida, 1994, p. 125, fig. 2c.

Material examined. 1♀, Cheonunsa Temple, Chungju, 1 Feb. 1995 (SH Kim); 1♂, 1♀, Mt. Seorak, 5 Sep. 1998 (SM Yoon); 1♀ (ovi.), stream, Gyeongju, 4 Apr. 1999 (CYC & JML); 1♂, 1♀, spring, Sintanjin, 27 May 2002 (JML); 6♀♀, Muncheonji Res., Gyeongsan, 30 Dec. 2002 (EH Kwon); 1♀, puddle, Seongsan, Jeju Is., 24 Jan. 2003 (CYC & JML); 1♀, Pond, Jeju Is. 28 Jan. 2003 (CYC & JML); 1♀, spring, Udo, Jeju Is., 28 Jan. 2003 (CYC & JML); 1♀ (ovi.), Sinji Res., Wando Is., 8 Feb. 2003 (CYC & JML); 1♀, Buheungcheon Str., Yeongdeok, 27 Feb. 2003 (CYC & JML); 1♀, Upo Swamp, Changnyeong, 11 Mar. 2003 (HS Rho); 1♀ (ovi.), puddle, Yongdang-ri, JeJu Is., 21 Mar. 2003 (CYC & JML); 1♀, Seyeonjeong pond, Bogil Is., 12 Apr. 2003 (JML); 1♀, Bogil Res., Bogil Is., 12 Apr. 2003 (JML); 9♀♀ (8 ovi.), Jahayeon Pond, Seoul National Univ., 12 Apr. 2003 (HS Rho); 1♀, Weolsong Swamp, Uljin, 1 May 2003 (CYC & JML); 1♀, Haepyeong Swamp, Gumi, 29 Apr. 2003 (SM Yoon); 2♀♀ (1 ovi.), Bongwha Res., Kimhae, 28 Jun. 2003 (KH Ahn); 1♀, puddle, Janggodo Is., Boryeong, 14 Jul. 2003 (JML, JMJ & KH

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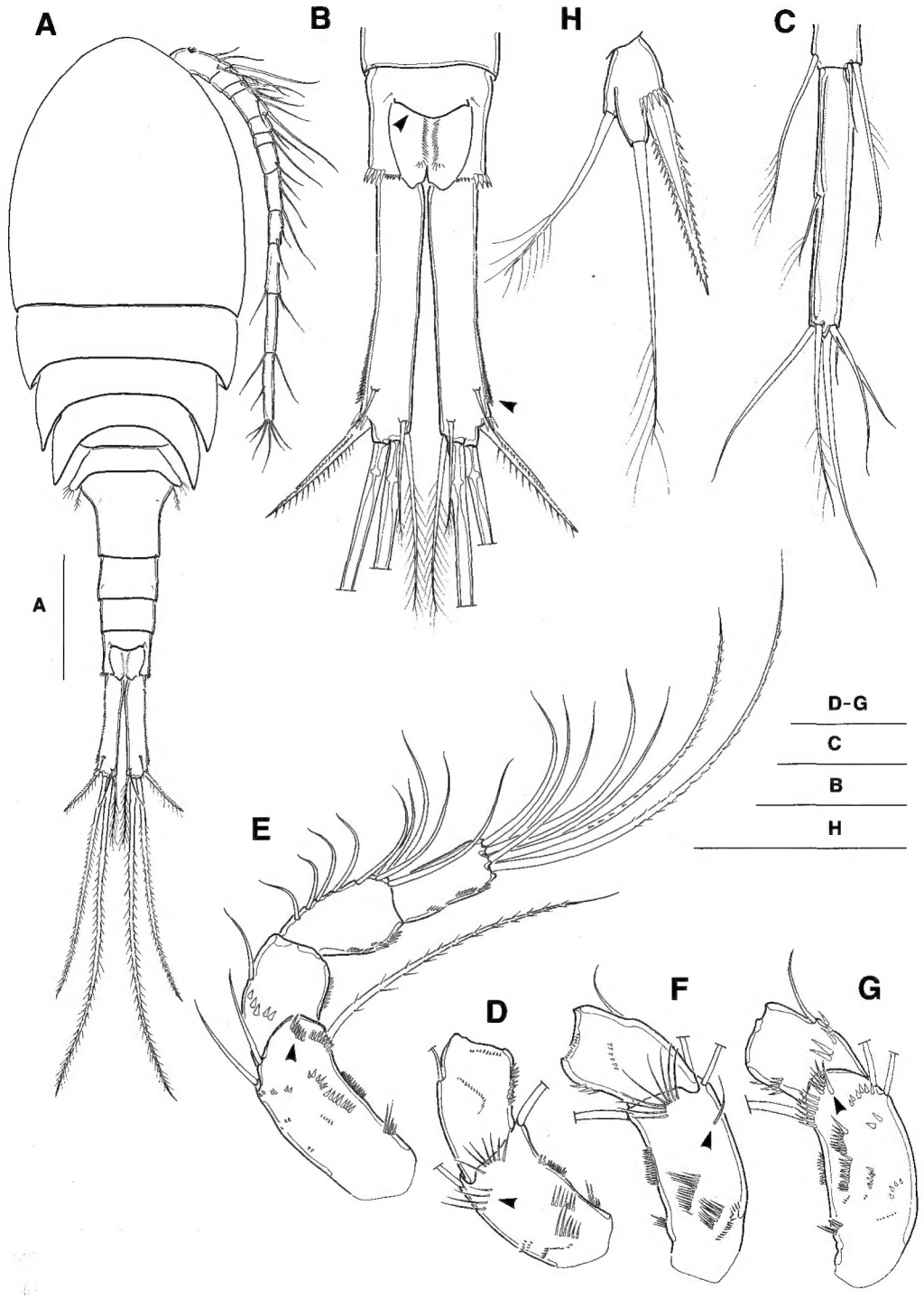

Fig. 1. *Eucyclops roseus* Ishida, female. A, habitus, dorsal; B, anal somite and Fu, dorsal; C, last segment of A1; D, A2 basis, anterior; E, A2 basis, posterior; F, A2 basis, anterior (variation); G, A2 basis, posterior (variation); H, P5. Scale bars = 0.05 mm (C-G), 0.1 mm (B, H), and 0.2 mm (A).

Ahn); 1♀ (ovi.), Geumgang R., Seocheon, 15 Jul. 2003 (CYC & JML); 3♀♀ (2 ovi.), puddle, Ungcheon, Boryeong, 15 Jul. 2003 (CYC & JML); 1♀, Judong Res., Jeongeup, 20 Jul. 2003 (JML); 1♀, Bujeon Res., 20 Jul. 2003 (JML); 2♀♀, Seorang Res., Hwaseong, 1 Aug. 2003 (JML); 1♀ (ovi.), Gonggeomji Res., Sangju, 23 Aug. 2003 (CYC & JML); 2♀♀ (2 ovi.), Jukbaek, Peongtaek, 17 Jan. 2004 (JML); 4♀♀ (2 ovi.), Namgang R., Jinju, 4 Feb. 2004 (CYC & JML); 3♀♀ (1 ovi.), Hamyeong, Yeongcheon, 24 Feb. 2004 (JMJ); 1♀, Nokjeon, Yeongcheon, 24 Feb. 2004 (JMJ); 1♀, Beolgyo Str., Boseong, 25 Feb. 2004 (CYC); 1♀, Yedangji Res., Boseong, 26 Feb. 2004 (CYC & JML); 2♀♀ (2 ovi.), Daegokri Res., Youngcheon, 27 Feb. 2004 (JMJ); 1♀, Undae Bridge, Gyeongju, 27 Feb. 2004 (JMJ & HJ Hyeon); 2♀♀ (2 ovi.), Pyeongchon, Uiryeong, 20 Mar. 2004 (JMJ & HJ Hyeon); 2♀♀ (2 ovi.), Cheongyecheon streamlet, Uiryeong 20 Mar. 2004 (JMJ & HJ Hyeon); 1♀, Buheung streamlet, Yeongdeok, 3 Apr. 2004 (CYC & JML); 3♀♀ (2 ovi.), puddle, Yeongcheon, 24 Apr. 2004 (JMJ); 1♀, Jeonggak-ri Res., Nonsan, 30 Apr. 2004 (HWL); 1♀, Jeongtosa Temple Res., Seocheon, 30 Apr. 2004 (HWL); 2♀♀, Geumrodong well, Youngcheon, 16 May 2004 (JMJ); 1♀, Jangwhari, Ganghwado, 21 May 2004 (JA Baek); 1♀, Namdaecheon R., Gangneung, 19 Jun. 2004 (JMJ); 1♀, Gosan, Jeju Is. 26 Jun. 2004 (GS Min); 2♀♀ (1 ovi.), Seongjukje Res., Jindo Is., 29 Jun. 2004 (JMJ & HWL); 2♀♀ (1 ovi.), Jeongji-ri streamlet, Jindo Is., 30 Jun. 2004 (GS Min & JA Baek); 1♀, Gahyangje Res, Jindo Is., 1 Jul. 2004 (JMJ & HWL); 1♀, Hupocheon estuary, Uljin, 4 Aug. 2004 (CYC, JML & JMJ); 4♀♀, streamlet, Gyeongju, 4 Sep. 2004 (CYC, JML & JMJ); 1♀, Yongmyeong-ri, Gyoengju, 6 Sep. 2004 (JML & JMJ); 1♀, Gamcheon, Yecheon, 13 Sep. 2004 (CYC); 2♀♀, puddle, Ulsan, 3 Oct. 2004 (CYC, JML & JMJ); 1♀, Upo Swamp, Changnyeong, 27 Nov. 2004 (CYC & JML); 2♀♀, puddle, Ganghwa Is., 13 Dec. 2004 (GS MIN); 1♂, 2♀♀ (1 ovi.), Byeonggok, Yeongdeok, 6 Jan. 2005 (JMJ & HWL); 2♀♀, Sinjeon Res. Changnyeong, 5 Feb. 2005 (CYC & JMJ).

Diagnosis. Body length 1.20-1.43 mm (n = 14, mean 1.28) in female (Fig. 1A); Fu elongate, about 4.5-6.5 times as long as broad, serrated along whole lateral margin (Figs. 1B, 3C); serration much stronger toward posterior end; lateralmost terminal (outer) caudal seta far away from lateral terminal caudal seta; Op apparently convex (Figs. 1B, 3C); hyaline membrane on last segment of A1 with smooth margin (Fig. 1C); A2 basis with 2 groups of hairs near distal margin of anterior face (Fig. 1D), with spinule row along distolateral margin of posterior face (Fig. 1E); Mxl palp with circular array of minute spinules (Figs. 2B, 3E); Mxa praecoxa with spinule row along ventrolateral face (Fig. 2C); P4 exp3 with relatively slender apical spine, a little longer than exp3 (Figs. 2H, 3F); P4 coupler with sparse hairs along distal margin (Fig. 2H); medial spine of P5 apparently thick and stout (Fig. 1H).

Remarks. *Eucyclops roseus* is the most frequent and abundant cyclopoid species in the littoral zone of freshwaters in Korea. Usually they tend to inhabit the stagnant and eutrophicated waters.

'*Eucyclops serrulatus*' reported from Youngsan Lake by Yoo and Lim (1989) should be corrected to this species in consideration of the position of lateralmost terminal (outer) caudal seta (far away from next terminal caudal seta), serration type (getting stronger toward posterior end of Fu), the hirsute P4 coupler (with 3-4 strong transverse rows of hairs on the posterior face of coupler), and the elongate apical spine on P4 exp3, although those were depicted rather insufficiently or inadequately in their figures. Likewise, most of the previous records reported from

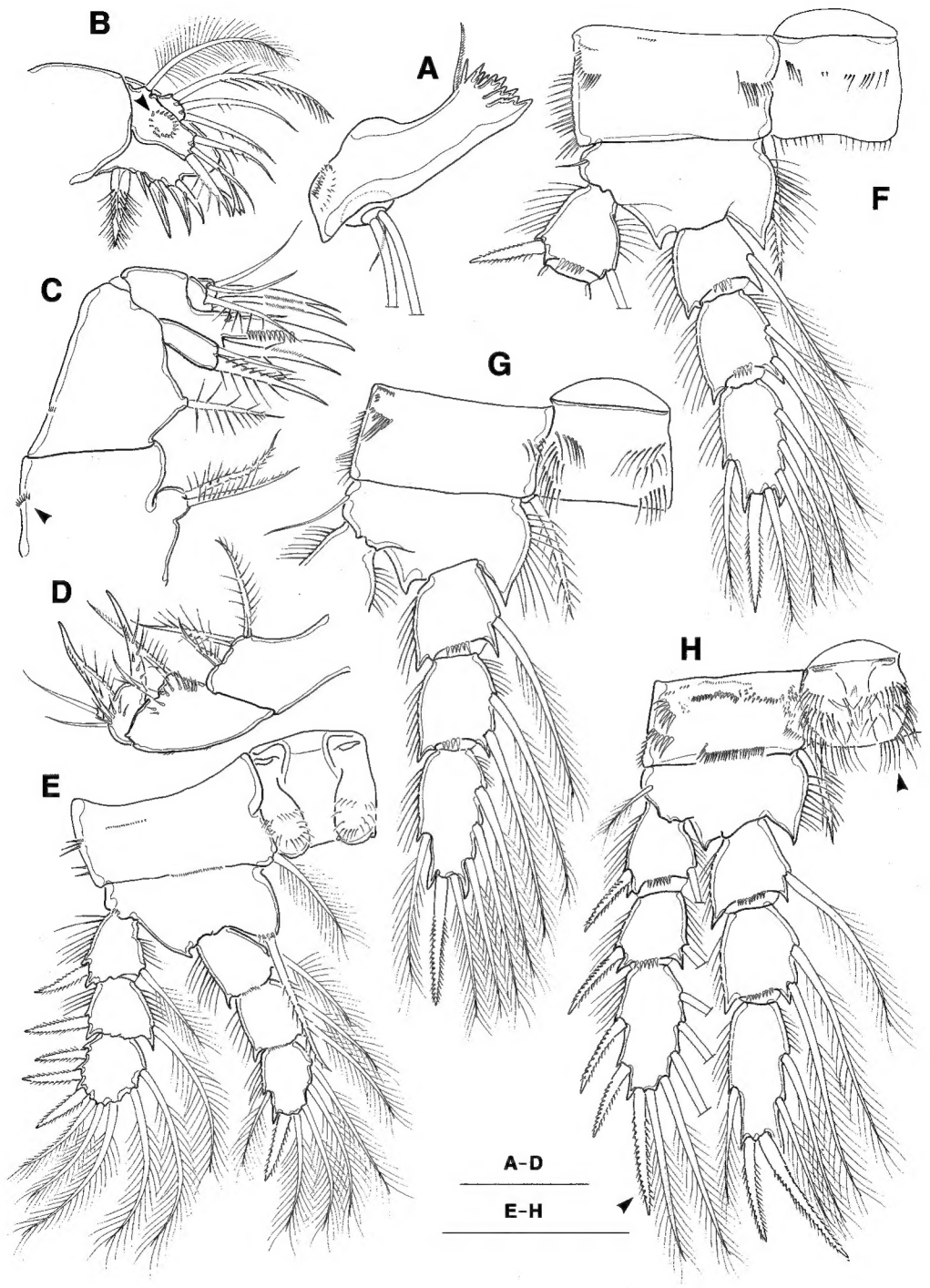

Fig. 2. *Eucyclops roseus* Ishida, female. A, Md; B, Mxl; C, Mxa; D, Mxp; E, P1, anterior; F, P2 enp and coupler, posterior; G, P3 enp and coupler, posterior; H, P4, posterior. Scale bars = 0.05 mm (A-D), and 0.1 mm (E-H).

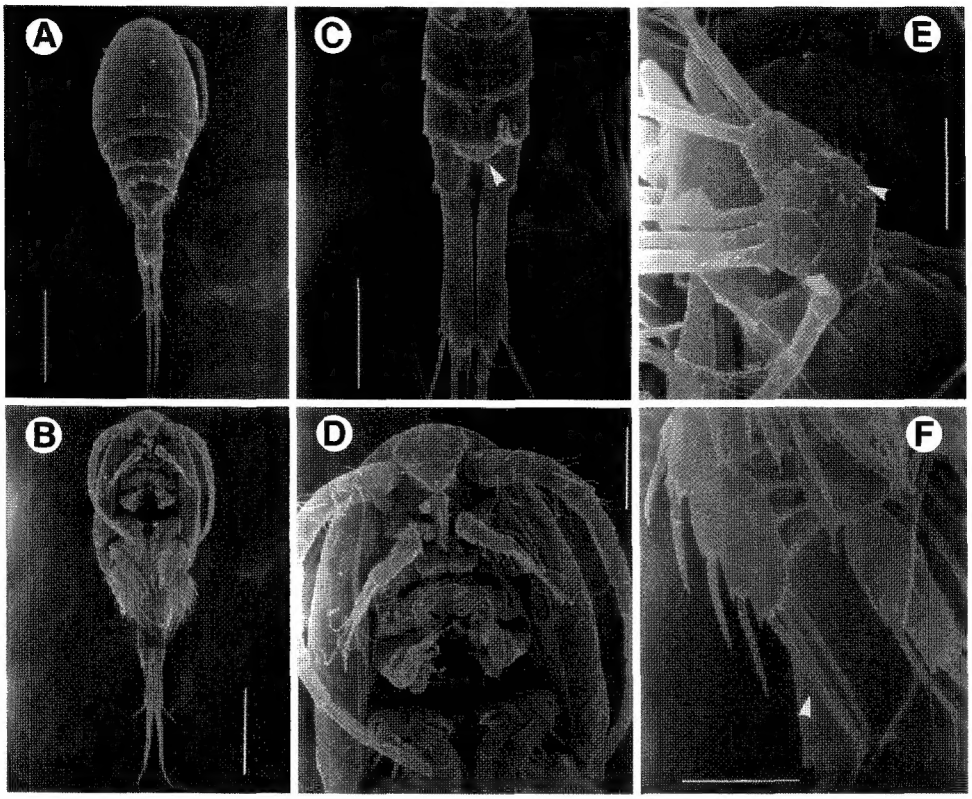

Fig. 3. *Eucyclops roseus* Ishida, female (SEM). A, habitus, dorsal; B, habitus, ventral; C, Op, anal somite and Fu, dorsal; D, mouth part; E, Mxl palp; F, P4 exp3. Scale bars = 0.015 mm (E), 0.05 mm (F), 0.1 mm (C, D), and 0.3 mm (A, B).

Korea as '*E. serrulatus*', that is, Kim and Chang (1989) and the numerous limnological studies, might be the misidentification of this species.

This species can be somewhat easily differentiated from other sibling species of *serrulatus* group by the conspicuously convex Op and the much stronger serration at distal portion of Fu (Figs. 1B, 3C). Korean specimens fit well with the original description (Ishida, 1997) except for the relatively more densely haired distal margin of P4 coupler (Fig. 2H). Furthermore, three variation forms were found: 10 of 32 (31.2%) specimens examined possessed a peculiarly long setule beside the medial margin of anterior face of A2 basis (Fig. 1F, arrow); 10 of 32 specimens examined (31.2%) had an additional setule posterior to the normal setule row on the posterior face of A2 basis (Fig. 1G, arrow); 11.4% of specimens examined did not show a setule row along the ventrolateral face of Mxa. They must be regarded as the intraspecific variations, because other important characters perfectly coincide with those of normal individuals or populations, moreover, they do not show the genetic divergences enough to be divided as distinct taxa each other in our unpublished mitochondrial COI data.

Distribution. Japan, Korea.

2. *Eucyclops serrulatus* (Fischer, 1851) (Fig. 4)

Cyclops serrulatus Fischer, 1851, p. 423, pl. 10, figs. 22-23, 26-31.

Eucyclops serrulatus: Kiefer, 1929, p. 31, fig. 12; Rylov, 1948, p. 139; Dussart, 1969, p. 40, fig. 10; Kim and Chang, 1989 (in part.), p. 232; Ishida, 2002, p. 45, fig. 6; Ishida, 2003, p. 2, figs. 1-3.

Material examined. 4♀♀, spring, Kangnung, 2 Aug. 1996 (CYC & JML); 2♂♂, 8♀♀, same locality, 28 Feb. 2005 (CYC, JML, JMJ & HWL); 1♂, 12♀♀, spring, Namae, Yangyang, 28 Feb. 2005 (CYC, JML, JMJ & HWL).

Diagnosis. Body length 0.96-1.09 mm (n = 7, mean 1.02) in female; Fu (Fig. 4A) elongate, about 4.5-6.5 times as long as broad, serration along about distal three quarters to more than 90% of lateral margin; serration not much stronger posteriorly; A2 basis lacking small spinules near distolateral corner of posterior face (Fig. 4C), furnished with 2 groups of hairs near distal margin of anterior face (Fig. 4D); Mxl palp lacking spinule array (Fig. 4F); Mxa praecoxa with spinule row along ventrolateral face (Fig. 4G); Op little convex (Fig. 4B); P4 exp3 with relatively slender and short apical spine, this spine about 0.6-0.9 times as long as exp3 (Fig. 4H); P4 coupler with an array of short and strong spiniform setules along posterior edge, all pointing medially (Fig. 4I).

Remarks. This species has been known as cosmopolitan, and reported from whole Europe, Africa (from Algeria to South Africa), Asia (Iran, India, Sri Lanka, Malaysia, Taiwan, China, Korea, Japan), America (Canada, U.S.A., Mexico, Panama, Chile, Brazil, Argentine), Australia, and New Zealand (Dussart and Defaye, 1985). However, in recent years this species turns out to be a species complex comprising many cryptic species. One of the most successful regional studies on the species group was achieved in Japan by Ishida (1998, 2000, 2001, 2002). Seven species belonging to *serrulatus* group were clarified in Japan, and among them five species were new to science. The existence of true *Eucyclops serrulatus* s. str. in the Far East was also confirmed with difficulty after the precise comparison with the reference specimens from type locality (St. Petersburg, Russia) (Ishida, 2001).

According to the redescription based upon Japanese specimens, this species is somewhat variable especially in the shape of P4 couplers and the ornamentation of A2. In the Korean specimens, the variations were also observed. On the distomedial corner of posterior face of A2 basis, two groups of hairs were recognized (Fig. 4D), but they were sometimes very weak, or even absent near the medial margin (Fig. 4E). The spinule or short-setule array on the distal margin of P4 coupler (Fig. 4I) is the decisive characteristics of this species as mentioned in Ishida (2002). As the setules are short and strong in compared with long, hairly ornamentation of other sibling species, they are usually shown as a spinular process and even as being serrated. The shape of a transverse array of spinules and lateral setule (or spinule) rows on the posterior face of P4 coupler showed a little variabilities depending on the individuals.

Specimens from a spring at Gangnung near eastern coast of Korea (37°45′59″N, 128°52′27″E) showed a tendency of weak serration of Fu, that is, extending only upto half or to less than proximal third of lateral margin of Fu, and sometimes asymmetrical (Fig. 4B). Furthermore, some specimens possessed an additional spinule array along distal margin of P3 coupler (Fig. 4K) as compared with typical form (Fig. 4J).

However, all the variations above are confirmed as coincided with or within the variation range

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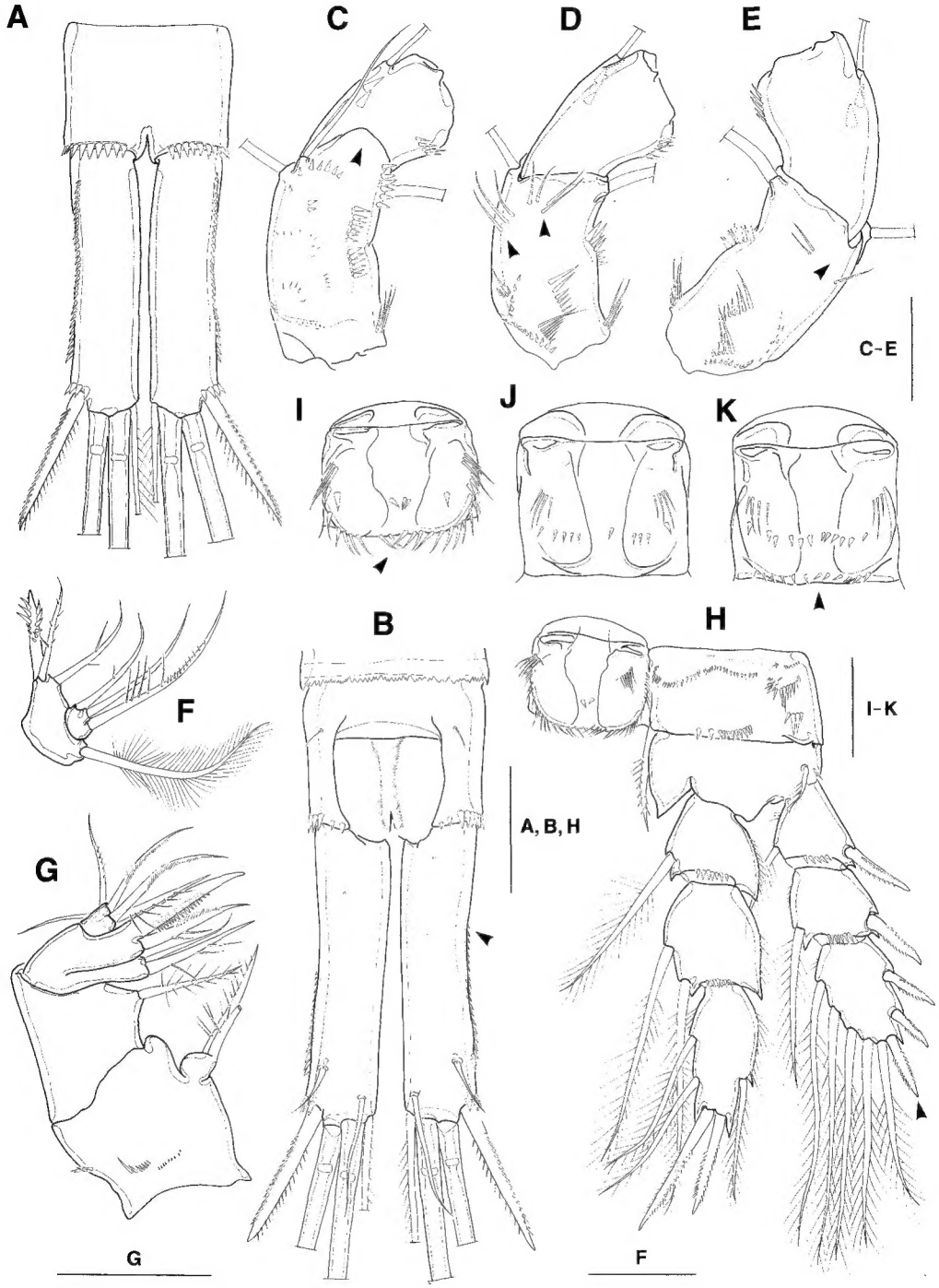

Fig. 4. *Eucyclops serrulatus* (Fischer), female. A, anal somite and Fu, ventral; B, anal somite and Fu (variation), dorsal; C, A2 basis, posterior; D, A2 basis, anterior; E, A2 basis, anterior (variation); F, Mxl palp and exopodite; G, Mxa; H, P4, posterior; I, P4 coupler, posterior; J, P3 coupler, posterior; K, P3 coupler (variation). Scale bars = 0.03 mm (C-F, I-K) and 0.05 mm (A, B, G, H).

of the Japanese specimens by Dr. T. Ishida (pers. comm.).

Ishida (2002) wrote that this species commonly occurred from mountain waters like springs, streamlets, and caldera lakes, therefore could be regarded as a cold-water species. The collection data from Korea, that is, two hillside springs around Taebaek Mountains, are in accord with his view.

Distribution. Europe, Japan, Korea.

3. *Eucyclops speratus* (Lilljeborg, 1901) (Fig. 5)

Cyclops varius var. *speratus* Lilljeborg, 1901, p. 88, figs. 12-15.

Eucyclops speratus: Kiefer, 1929, p. 33; Ishida and Hiruta, 1999, p. 87, figs. 1-2; Ishida, 2002, p. 46, fig. 7.

Material examined. 2♀♀, Janghyeon Res., Boryeong, 14 Jul. 2003 (CYC); 1♀, ditch, Seonunsa Temple, Gochang, 20 Jul. 2003 (JML); 7♀♀ (4 ovi.), Seorang Res., Hwaseong, 1 Aug. 2003 (JML); 1♀, streamlet, Cheongganjeong, Goseong, 12 Feb. 2004 (HWL); 6♀♀ (2 ovi.), Hamyeong Res., Yeongcheon, 24 Feb. 2004 (JMJ); 2♀♀ (1 ovi.), Gamchoncheon Str., Gyeongju, 27 Feb. 2004 (CYC, JML & JMJ); 1♀, Cheongyecheon streamlet, Uiryeong, 20 Mar. 2004 (JMJ & HJ Hyeon); 1♀, Tobong Res., Yeongcheon, 24 Apr. 2004 (JMJ); 1♀, Dongcheongyo Br., Gongju, 27 Apr. 2004 (JMJ & HWL); 1♀, Namdaecheon R., Gangneung, 19 Jun. 2004 (JMJ); 2♀♀, ricefield, Gyeongsan, 24 Jun. 2004, (CYC & JMJ); 1♀, Bojeonpo, Jindo Is., 29 Jun. 2004 (JMJ & HWL); 1♀, puddle, Jeopdoipgu, Jindo Is., 30 Jun. 2004 (JMJ & HWL); 1♀, Aegiji Res., Gyeongju, 4 Sep. 2004 (CYC, JML & JMJ); 1♀, puddle, Ganghwa Is., 5 Sep. 2004 (GS Min); 2♀♀, Majeonji Res., Uiseong, 9 Sep. 2004 (CYC & JMJ); 1♀, ditch, Yecheon, 13 Sep. 2004 (CYC & JMJ); 1♀, Daejongcheon Str., Gyoengju, 1 Oct. 2004 (JMJ & HWL); 2♀♀ (1 ovi.), Geumcheon Str., Ulsan, 3 Oct. 2004 (CYC, JML & JMJ); 1♀, estuary of Han R., 4 Oct. 2004 (HS Rho); 2♀♀ (1 ovi.), Sinpyeong Res., Gyeongju, 7 Oct. 2004 (JML, JMJ & HWL); 2♀♀, Munsanji Res., Yeongcheon, 16 Oct. 2004 (CYC & JMJ); 1♀, Songgot Res., Changnyeong, 27 Nov. 2004 (CYC & JML); 1♀, Nakdong R., Mulgeum, 24 Jan. 2005 (JMJ & JJ Lee).

Diagnosis. Body length 1.04-1.39 mm (n = 5, mean 1.23) in female; serration on lateral margin of Fu extending nearly to anterior end, not much stronger posteriorly (Fig. 5A); Op with posterior margin slightly rounded; A2 basis without hairs near distomedial corner of anterior face (Fig. 5B), with several small spinules near distolateral margin of posterior face (Fig. 5C); Mxl palp with minute spinules (Fig. 5F); Mxa praecoxa usually lacking spinular row along ventrolateral face, but sometimes with a row of weak spinules (Fig. 5H); P4 exp3 with stout apical spine, nearly as long as exp3 (Fig. 5I); P4 coupler with rather long and strong hairs along distolateral edge.

Remarks. *Eucyclops speratus* usually occurred in the littoral zone of small reservoirs or in the ditches for irrigation, which were often eutrophicated.

In the spinular ornamentation at the distomedial corner of posterior face of A2 basis, three variation forms exist (Fig. 5C-E), of which the variation form shown in Fig. 5C is general in Korea. The spinular ornamentation on Mxl palp is a little variable, sometimes with only a few spinules (Fig. 5F), but usually forming a row of 8-9 spinules (Fig. 5G). As mentioned in the reports from Japan (Ishida and Hiruta, 1999; Ishida, 2002), the spinulation on ventrolateral face of Mxa praecoxa is also variable in Korean specimens, that is, usually with a row of weak spinules (Fig. 5H), but

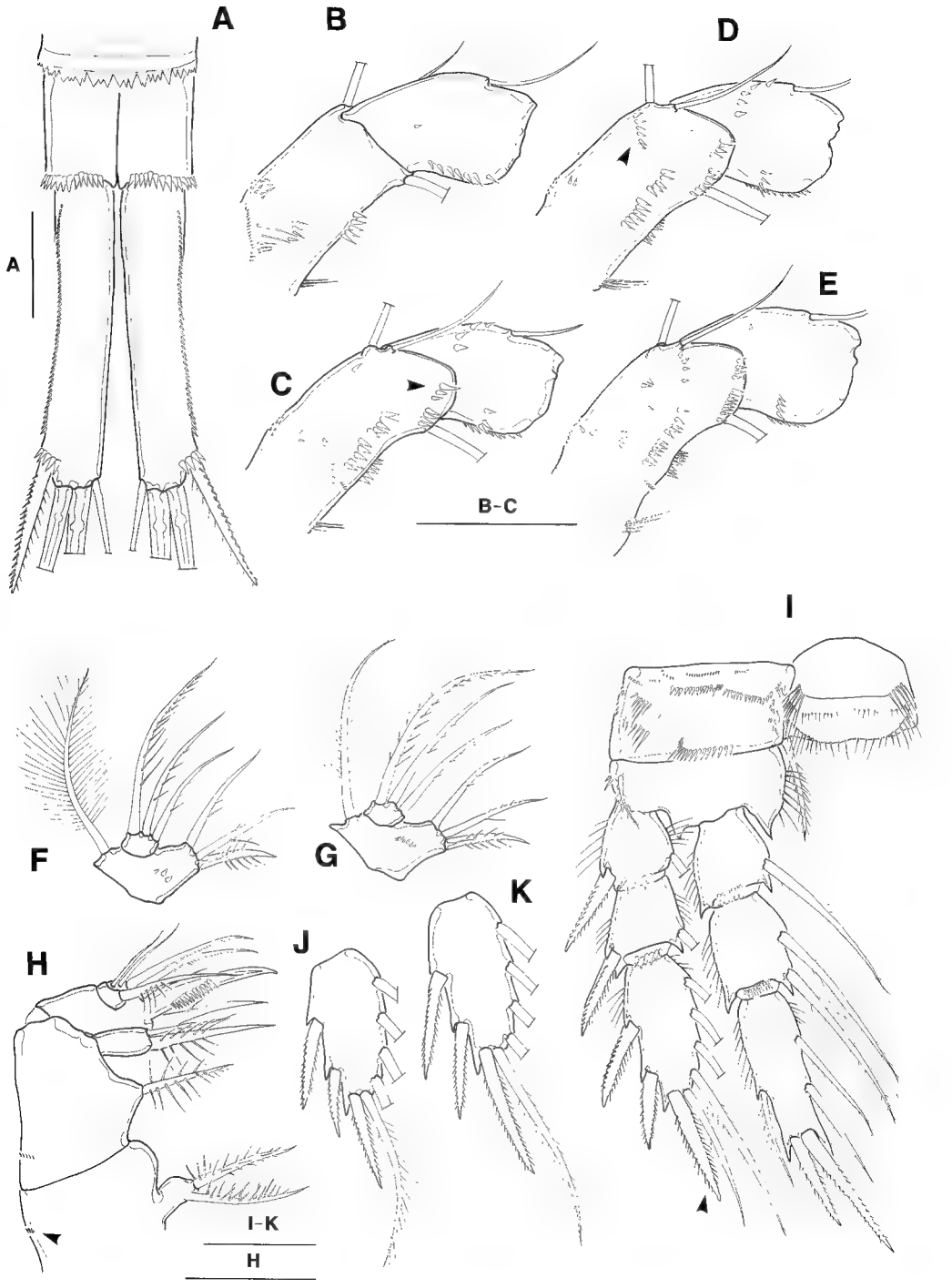

Fig. 5. *Eucyclops speratus* (Lilljeborg), female. A, anal somite and Fu, ventral; B, A2 basis, anterior; C, A2 basis, posterior; D-E, A2 basis, posterior (variation); F, Mxl palp; G, Mxl palp (variation); H, Mxa; I, P4, posterior; J-K, P4 exp3 (variation). Scale bars = 0.05 mm.

sometimes bare. Korean specimens show the discrepancy from the Japanese specimens by the relatively short apical spine on P4 exp3, which is nearly as long as exp3, and relatively slender in Koreans (Fig. 5I-K), while conspicuously stout and much longer than exp3 in Japanese specimens (cf. Ishida, 2002, Fig. 7 m).

Distribution. Japan, Korea.

4. **Eucyclops pacificus* Ishida, 2000 (Fig. 6)

Eucyclops pacificus Ishida, 2000, p. 22, figs. 1-3; Ishida, 2002, p. 46, fig. 8.

Material examined. 2♀♀, well, Pohang, 23 Jul. 1990 (CYC); 1♂, 4♀♀, mountain trickle, Songgwangam Tample, Gugeumdo Is., 1 Aug. 2002 (JML); 1♂, 5♀♀ (1 ovi.), spring, Gyeongsan, 2 Aug. 2004 (CYC, JML & JMJ); 1♀, streamlet, Gyeongju, 4 Sep. 2004 (CYC, JML & JMJ); 2♀♀ (2 ovi.), spring, Mt. Hambak, Changnyeong, 21 Oct. 2004 (JMJ).

Diagnosis. Body length 1.07-1.26 mm (n = 5, mean 1.17) in female; serration on lateral margin of Fu weak, extending nearly to anterior end, not so strong and acute near posterior end of Fu (Fig. 6A); Op with posterior margin gently rounded; A2 basis with 2 groups of long and strong hairs near distal margin of anterior face (Fig. 6B), with several spinules along distolateral margin of posterior face (Fig. 6C); Mxl palp with semi-circular array of minute spinules (Fig. 6F); Mxa praecoxa with rather strong spinule row along ventrolateral face (Fig. 6I); apical spine of P4 exp3 slender, about two thirds as long as exp3 (Fig. 6J); P4 coupler with rather strong hairs along distolateral corner (Fig. 6J).

Remarks. This species is relatively rare in Korea, and occurred from rather cold and oligosaprobic waters like springs and mountain trickles.

Eucyclops pacificus most resembles *E. serrulatus* among the sibling species from Korea in the general appearances of Fu, spinule ornamentation of Mxl and Mxa, and similar type of habitats, however, it is discriminated from *E. serrulatus* by the ornamentation of A2 basis (with spinules near distolateral corner of posterior face in *E. pacificus*, while lacking in *E. serrulatus*) and P4 coupler (with long hairs along distal edge in *E. pacificus*, while with an array of short and strong setules on distal edge in *E. serrulatus*). Korean specimens coincide with the original description from Japan (Ishida, 2000), except for the stronger spinule array on the distomedial corner of posterior surface of A2 basis (Fig. 6C, E).

Korean specimens show some variabilities in the arrangement of hairs on anterior surface of A2 basis (the hairs are sometimes divided into two groups, lateral one of which much extending posteriorly than in normal case) (Fig. 6D) and the relative length of apical spine on P4 exp3 (ranging from 65.7 to 95.6% of P4 exp3) (Fig. 6K, L). The shape of spinule array on Mxl palp is also somewhat variable, generally semi-circular (Fig. 6F), but sometimes one or two oblique row (s) of a few spinules (Fig. 6G, H)

Distribution. Japan, Korea.

**5. *Eucyclops ohtakai* Ishida, 2000 (Fig. 7)

Eucyclops ohtakai Ishida, 2000, p. 25, figs. 4-5; Ishida, 2002, p. 46, fig. 9.

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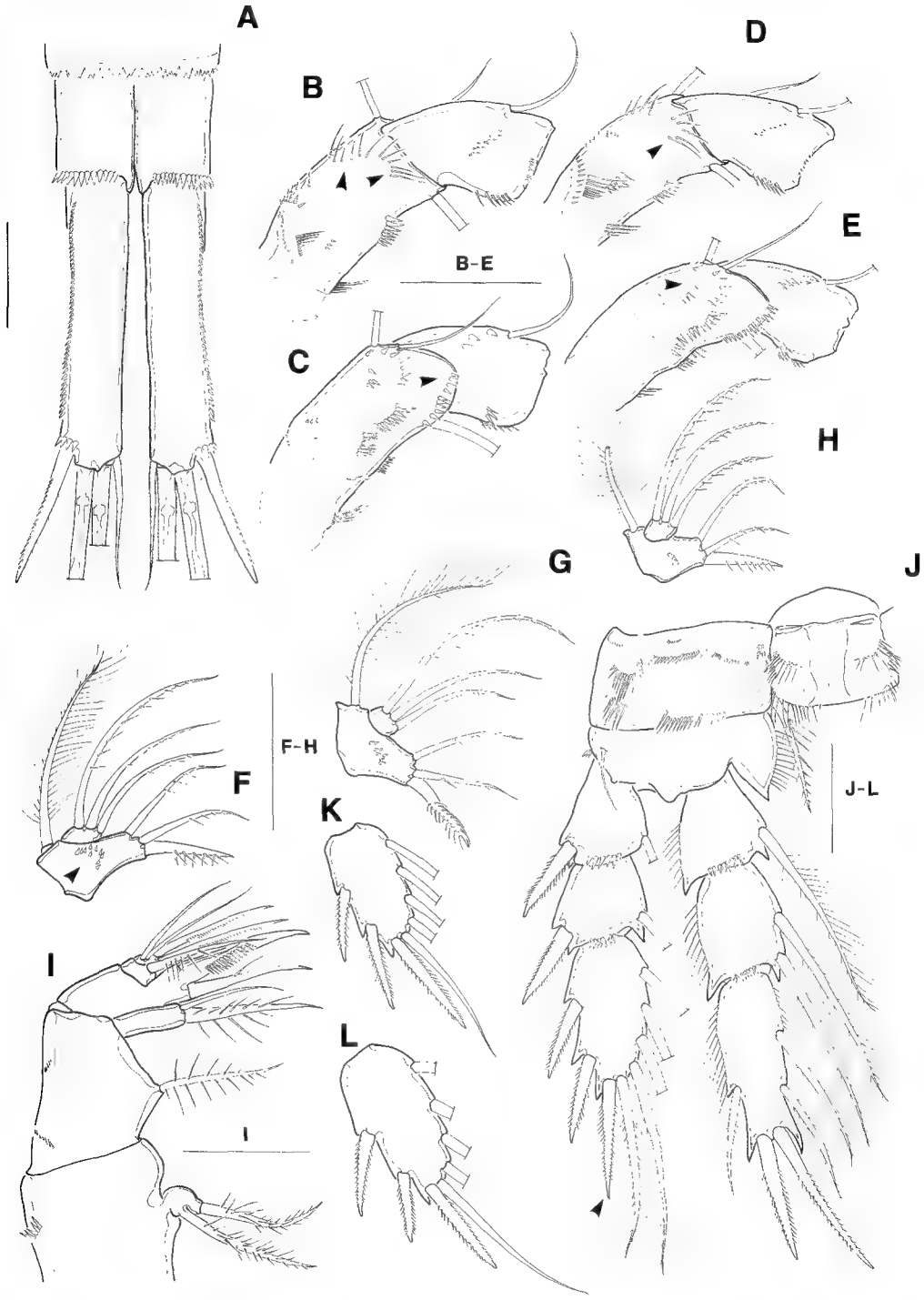

Fig. 6. *Eucyclops pacificus* Ishida, female. A, anal somite and Fu, ventral; B, A2 basis, anterior; C, A2 basis posterior; D, A2 basis, anterior (variation); E, A2 basis, posterior (variation); F, Mxl palp and exopodite; G, H Mxl palp and exopodite (variations); I, Mxa; J, P4, posterior; K-L, P4 exp3 (variation). Scale bars = 0.05 mm.

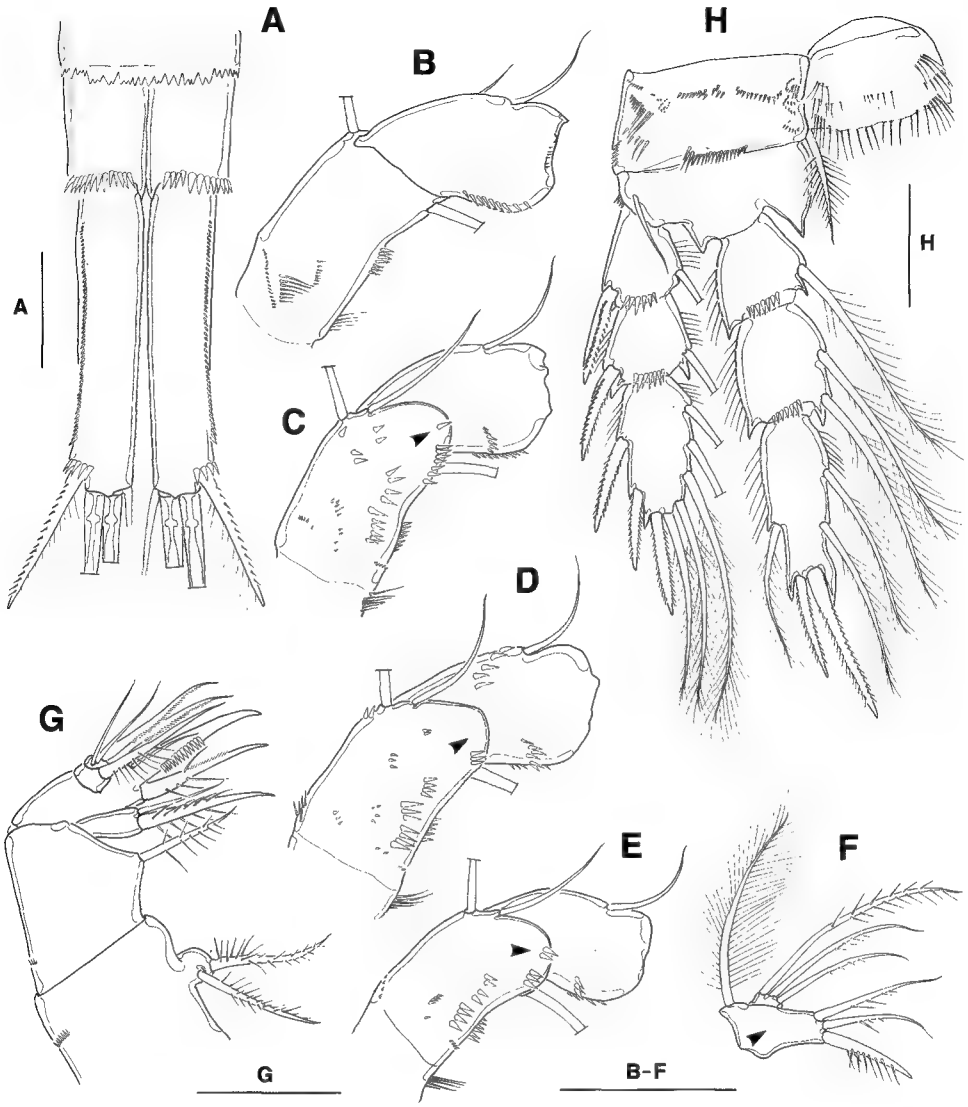

Fig. 7. *Eucyclops ohtakai* Ishida, female. A, anal somite and Fu, ventral; B, A2 basis, anterior; C, A2 basis, posterior; D-E, A2 basis, posterior (variation); F, Mxl palp and exopodite; G, Mxa; H, P4, posterior. Scale bars = 0.05 mm.

Material examined. 3♀♀, puddle, Mt. Halla, Jeju Is., 26 Jan. 2003 (CYC & JML); 1♀, streamlet, Mt. Halla, Jeju Is., 27 Jan. 2003 (CYC & JML); 2♀♀, Mihwangsa Res., Haenam, 8 Feb. 2003 (CYC & JML); 1♀ (ovi.), pond, Gangjin, 9 Feb. 2003 (CYC & JML); 1♀, Dugyecheon Str., Nonsan, 15 Jul. 2003 (CYC, JML & JMJ); 3♀♀, ditch, Seonunsa Temple, Gochang, 20 Jul. 2003 (JML); 1♀, Judong Res., Jeongeup, 20 Jul. 2003 (JML); 2♀♀, Bujeon Res., 20 Jul. 2003 (JML); 3♀♀ (1 ovi.), pond, Chungnam Univ., Daejeon, 19 Aug. 2003 (CYC, JML & JMJ); 2♀♀ (2 ovi.), puddle, Samcheok, 26 Oct. 2003 (JMJ); 1♀, Sa-ri Res., Yeongcheon, 16 Jan. 2004

(JMJ); 1♀, Geumgang R., Okcheon, 15 Feb. 2004 (JML); 2♀ ♀ (2 ovi.), pond, Yeongcheon, 24 Feb. 2004 (JMJ); 3♀ ♀ (1 ovi.), Hamyeong Res., Yeongcheon, 24 Feb. 2004 (JMJ); 1♀, Beolgyocheon Str., Boseong, 25 Feb. 2004 (CYC); 1♀, Yedang Res., Boseong, 26 Feb. 2004 (CYC); 1♀, Sapgyoho Lake, Asan, 27 Apr. 2004 (HWL); 1♀, Imha Dam, Andong, 28 Apr. 2004 (JJ Lee); 1♀, Nonsan Res., 30 Apr. 2004 (HWL); 1♀, Jeongtosa Res., Seocheon, 30 Apr. 2004 (HWL); 1♀, Eunpa Res., Gunsan, 4 Jun. 2004 (JMJ); 3♀ ♀ (1 ovi.), Yeonhwaji Swamp, Gyeongsan, 24 Jun. 2004 (CYC & JMJ); 1♀, puddle, Gosan, Jeju Is., 26 Jun. 2004 (GS Min); 4 ♀ ♀ (1 ovi.), Sannaeje Res., Jindo Is., 1 Jul. 2004 (JMJ & HWL); 1♀, Yeonhwaji Res., Haenam, 13 Aug. 2004 (JML); 1♀, Chojijin Res., Ganghwado Is., 5 Sep. 2004 (GS Min); 1♀, streamlet, Gyeongju, 6 Sep. 2004 (CYC, JML & JMJ); 2♀ ♀ (1 ovi.), mountain puddle, Andong, 9 Sep. 2004 (CYC & JMJ); 2♀ ♀ (2 ovi.), Daehwa Str., Pohang, 7 Oct. 2004 (JML, JMJ & HWL); 1♀ (ovi.), ditch, Jindo Is., 18 Oct. 2004 (JMJ & HWL); 2♀ ♀, Gugyeoji Res., Changnyeong, 21 Oct. 2004 (JMJ); 3♀ ♀ (2 ovi.), Upo Swamp, Changnyeong, 27 Nov. 2004 (CYC & JML).

Diagnosis. Body length 1.03-1.49 mm (n = 11, mean 1.23) in female; serration on lateral margin of Fu weak, but extending nearly to anterior end, not so strong and acute near posterior end of Fu (Fig. 7A); Op with posterior margin gently rounded; A2 basis without hairs near distal margin of anterior face (Fig. 7B), with a few small spinules near distolateral margin of posterior face (Fig. 7C); Mxl palp without row of minute spinules (Fig. 7F); Mxa praecoxa with feeble spinule row along ventrolateral face (Fig. 7G); P4 exp3 with relatively slender apical spine, about two thirds as long as exp3 (Fig. 7H); P4 coupler with hairs sparsely along distal margin (Fig. 7H).

Remarks. *Eucyclops ohtakai* is the second commonest species in the *serrulatus* species group from Korea, and usually found in the detritus-rich littoral zone of reservoirs and streams. This species sometimes co-occurred with *E. roseus* (from 14 of 40 localities) and with *E. speratus* (from 5 of 40 localities) in Korea. Even in two locations, the three species were found together.

Eucyclops ohtakai is most similar to *E. speratus*. The only decisive morphological difference between them is the presence or not of spinulation on the lateral face of Mxl palp (absent in *E. ohtakai*, against present in *E. speratus*). The other two discriminative characters are the shape and relative length of apical spine of P4 exp3 and the spinule ornamentation on the distolateral corner of posterior face of A2 basis. However, the former is much variable in *E. speratus*, and the latter, as mentioned in the original description (Ishida, 2000), shows two variation forms also in Korean population, that is, mainly with a few spinules along distolateral margin (Fig. 7C, E), while sometimes without the spinules (Fig. 7D). All the Korean specimens examined have the P4 coupler with sparsely haired along distal margin (Fig. 7H), as in the original description, while nearly bare in the figure of Ishida (2002).

Distribution. Japan, Far East Russia (South Primorye), Korea.

6. **Eucyclops tsushimensis* Ishida, 2001 (Fig. 8)

Eucyclops tsushimensis Ishida, 2001, p. 54, figs. 3-4; Ishida, 2002, p. 47, fig. 11.

Material examined. 1♂, 1♀, mountain trickle, Songgwangam Temple, Geogeumdo Is., 1 Aug. 2002 (JML); 2♀ ♀, Yedangji Res., Boseong, 9 Feb. 2003 (CYC & JML).

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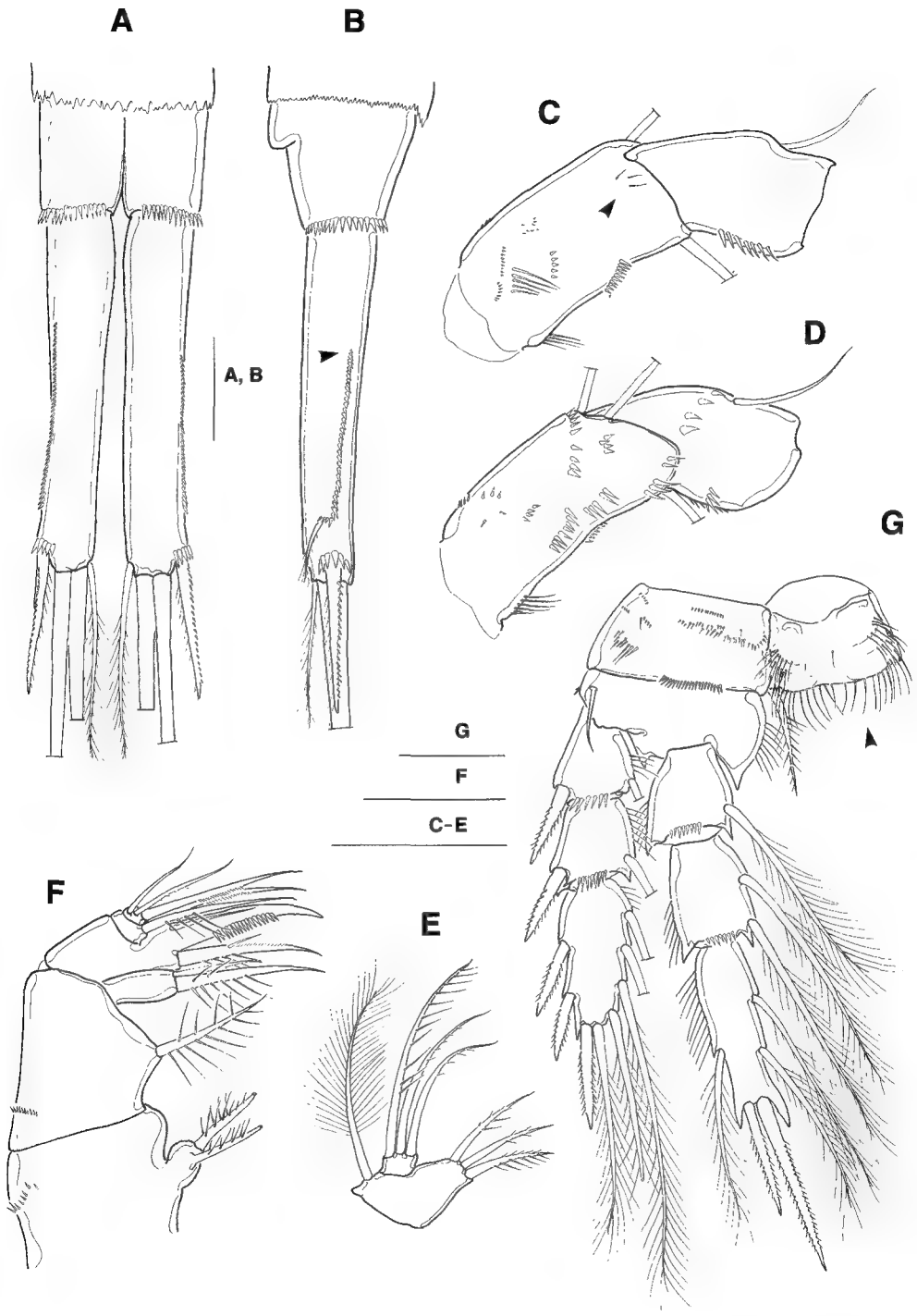

Fig. 8. *Eucyclops tsushimensis* Ishida, female. A, anal somite and Fu, ventral; B, anal somite and Fu, lateral; C, A2 basis, anterior; D, A2 basis, posterior; E, Mxl palp and exopodite; F, Mxa; G, P4, posterior. Scale bars = 0.05 mm.

Diagnosis. Body length 1.05-1.21 mm in female; serration on lateral margin of Fu weak and not getting stronger near posterior end, reaching about proximal one third of Fu (Fig. 8A, B); Op with posterior margin gently rounded; A2 basis with a few hairs sparsely present near distomedial corner of anterior face (Fig. 8C), with several spinules near distolateral margin of posterior face (Fig. 8D); Mxl palp without minute spinules on lateral face (Fig. 8E); Mxa praecoxa with spinules along ventrolateral face (Fig. 8F); P4 exp3 with slender apical spine, about two thirds as long as exp3 (Fig. 8G); P4 coupler with a little long and strong hairs along distal margin (Fig. 8G).

Remarks. *Eucyclops tsushimensis* was described from the littoral zone of mountain streamlet at Tsushima Is. (Ishida, 2001), only 49.5 km apart from the southeast coast of Korea. This species was found in a reservoir and a mountain trickle in the vicinity of southern coast of Korea. From the latter location, a mountain trickle of Gugeumdo Is., *E. tsushimensis* co-occurred with *E. pacificus*. It seems to favour cold and oligosaprobic waters, not far from the seashore.

Eucyclops tsushimensis is clearly differentiated from the other Korean members of the *serrulatus* group in having the short Fu serration (Fig. 8A, B), and the weak and sparse hairs near distal margin of anterior face of A2 basis (Fig. 8C). Serration of Fu is a little variable, and sometimes asymmetrical, that is, a specimen from Yedang Reservoir, Korea shows the serration extending to the level of 30.1% from the anterior end of Fu in one side, and 39.8% in the other side, while a topotype specimen from the type locality (Izuhara, Tsushima Is., Japan) shows the serration of 32.7% in one side and 34.2% in the other side. Korean specimens are coincided with the original description except for the relatively shorter and sparse hairs on the distal margin of P4 coupler (Fig. 8G) in compared with the Japanese specimens (cf. Ishida, 2001, Fig. 4e).

Distribution. Japan (Tsushima Is., Kyushu), Korea.

Based upon the previous records from Japan (Ishida, 1998, 2000, 2001, 2002) and the Far East Russia (South Primorye) (Ishida, 1997) and data of the present study, a key to the *Eucyclops serrulatus* group from the Far East is prepared.

A key to the *Eucyclops serrulatus* group from the Far East

1. Serration on lateral margin of Fu extending nearly to anterior end 2
   Serration of Fu weak, usually not reaching proximal third of Fu 6
2. A2 basis without hair near distal margin of anterior face 3
   A2 basis with hairs near distal margin of anterior face 4
3. Mxl palp with row of minute spinules ..... *E. speratus*
   Mxl palp without row of minute spinules ..... *E. ohtakai*
4. Op conspicuously convex; serration of Fu acute and stronger near posterior end ..... *E. roseus*
   Op with posterior margin gently rounded; serration of Fu not so acute and not stronger near posterior end of Fu 5
5. A2 basis smooth near distolateral corner of posterior face; P4 coupler with an array of short and strong setules on distal edge, pointing medially ..... *E. serrulatus*
   A2 basis with spinules near distolateral corner of posterior face; long hairs along distal edge of P4 coupler ..... *E. pacificus*

6. Fu serration confined to near lateral caudal seta; A2 basis lacking hairs near distomedial corner of anterior face and spinule row near distolateral corner of posterior face ..... *E. biwensis*
Fu serration reaching about proximal third of Fu; A2 basis with a few hairs near distomedial corner of anterior face and a spinule row near distolateral corner of posterior face ..... *E. tsushimensis*

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한국산 톱니꼬리검물벼룩 복합군(요각아강, 검물벼룩목, 검물벼룩과)의 분류

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요 약

한국 담수산 검물벼룩류에 대한 분류학적 연구의 일환으로, 톱니꼬리검물벼룩(*Eucyclops serrulatus*) 복합군에 속하는 6종을 보고한다: 톱니꼬리검물벼룩(*E. serrulatus*), 예쁜톱니꼬리검물벼룩(*E. roseus*), 큰가시톱니꼬리검물벼룩(*E. speratus*), 태평톱니꼬리검물벼룩(*E. pacificus*), 대머리톱니꼬리검물벼룩(*E. ohtakai*), 대마톱니꼬리검물벼룩(*E. tsushimensis*). 한국에서는 지금까지 다수의 보고서와 논문을 통해 톱니꼬리검물벼룩(*E. serrulatus*) 1종으로 기록되어 있었으나, 본 연구를 통해 이것이 6종의 자매종으로 구성된 복합군임을 확인하였다. 자매종간 분류학적 미세 형질을 서로 비교하였고, 종내 변이성에 대하여도 고찰하였다. 현재까지 극동아시아에서 기록된 톱니꼬리검물벼룩 복합군의 종 검색표를 작성하였다.